SECTION II.—GENERAL METEOROLOGY.

WORKING UP OF WIND OBSERVATIONS.

By J. W. SANDSTRÖM.

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Among the magnitudes observed and recorded by meteorologists the wind is the only one that possesses vector qualities. All the rest are scalar quantities. In discussing wind observations this distinction must be considered.

An important method of working up meteorological elements consists in deducing the monthly means of the same. The average, as every one knows, is obtained by taking the sum of the observations for the month and dividing it by the number of observations. To secure such an average for the wind, the sums of the wind vectors are taken and divided by the sum of the observations; the result obtained is the mean wind vector for the month.

There are various ways of determining the vector sums. One can proceed numerically by resolving the wind vectors into components referred to two mutually perpendicular axes, adding the components of either axis and finally combining the sums into a vector. One can also employ graphical methods, combining the wind vectors according to the law of parallelograms or constructing a polygon. Finally the sum can be ascertained mechanically by weighing or by plotting. I have tried all of these methods and have found that the last-named leads most quickly and most easily to the desired result.[1]

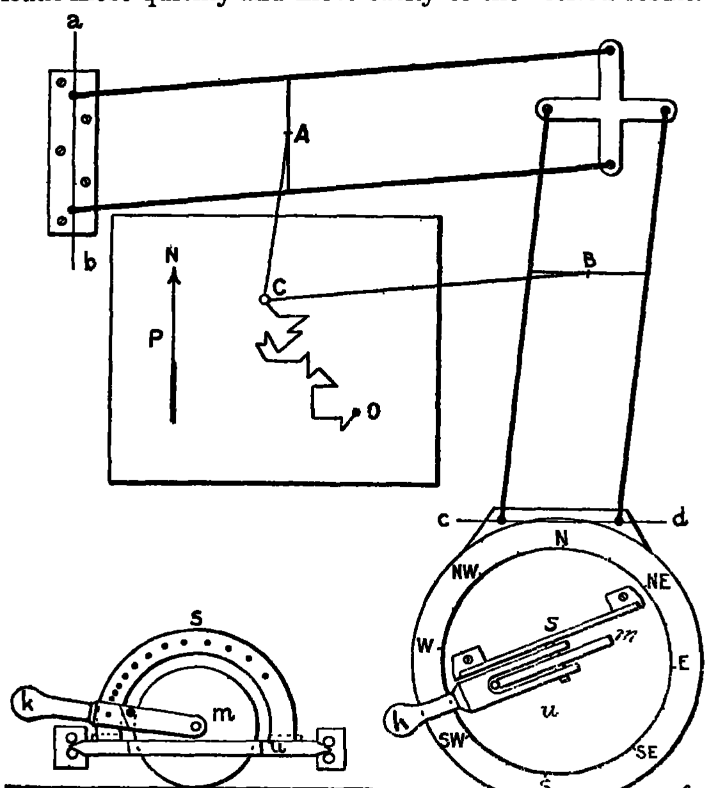

FIG. 1.—Sandström's device for mechanically plotting and adding wind vectors.

I will describe this process more in detail. Figure 1 shows a parallelogram linkage mounted on a drawing board so that the line *cd* always remains perpendicular to the fixed line *ab*, whatever the position of *cd*. A circular rim bearing the wind directions is connected with *cd*. This circle can be moved across the board in any direction but can not be rotated. The north-south direction of the circle always remains parallel to the fixed line *ab*. Within the circular rim and in its plane, lies a circular disk *u* which runs in a ball bearing in the inner edge of the circle and consequently can be set for the different wind directions by means of the handle *k*. A slot in the disk *u* accommodates the vertical wheel *m*, which can be made to turn by a friction clutch when we raise the handle *k* but remains stationary when *k* is lowered. Since the apparatus rests upon the wheel *m*, its movement is regulated by the movement of *k*, which is controlled by the scale *S*, on which the wind forces have been inscribed.

On the parallel linkage is a pantograph arrangement *ABC*, carrying a pen at *C*, which registers the movement of the apparatus in a reduced diagram *OC*. The curve *OC* then includes both the individual vectors and their sum.

The ruled paper on which the curve is traced is so oriented that its lines will coincide with the north-south direction of the instrument, and as a check the north-pointing arrow *P* is drawn before beginning to draw the vector diagram *OC*. If we imagine the points *O* and *C* in figure 1 connected by a straight line the direction and length of this line is the sum of all the small vectors of various directions which are drawn between *O* and *C*. For reading off these vector sums I have a special scale which is used like a protractor. (See fig. 2.) The circle of the protractor is divided into 40 parts, so that 0 or 40 represents the east direction, 10 the north, 20 the west, and 30 the south direction. Thus the tens indicate directly the quadrant of the vector direction.

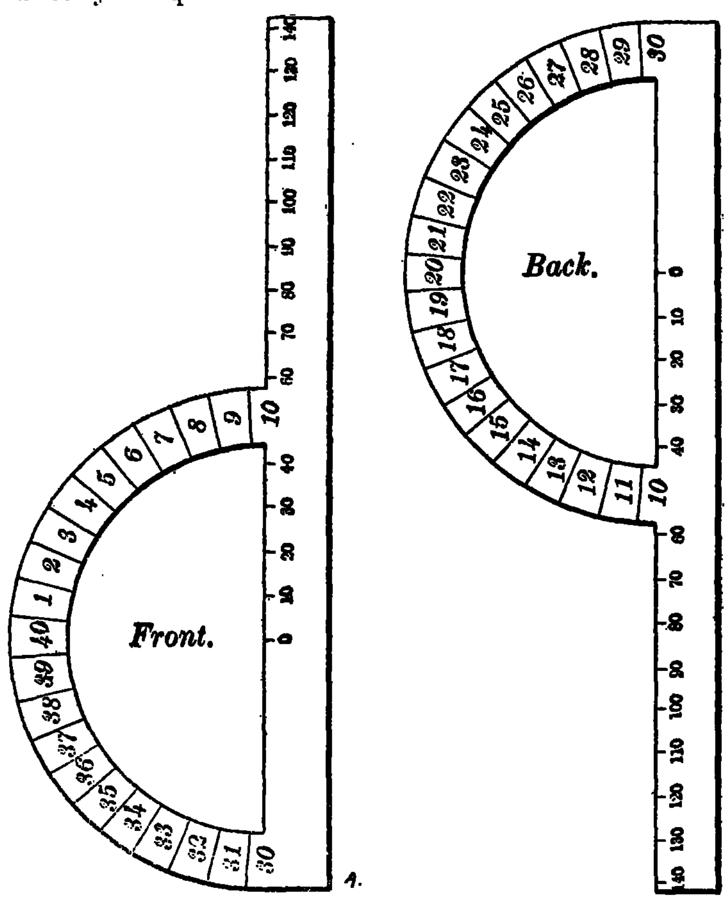

FIG. 2.—Sandström's scales for measuring the wind vectors and sums plotted by means of the device shown in figure 1.

The length *OC* represents the sum of the vectors. In my apparatus I have so chosen the scale *S* of figure 1 and the reduction *ABC* that a wind velocity of 1 meter per second corresponds to 0.5mm. on the curve *OC*. The length *OC* will be measured by a corresponding scale. If, for example, one wishes to compute the total wind

[1] Descriptions of some other devices for determining wind resultants are given in this REVIEW, December, 1897, 25: 540, fig.—EDITOR.

movement for the month from the daily 8 a. m. observations, he will, of course, multiply the vector sum by 86,400. This factor can then be appropriately considered in constructing the scale so that one may read off the wind movement directly in kilometers. This sum divided by the number of days in the month gives the average air movement for 24 hours, which is conveniently entered on the monthly chart as an arrow drawn to scale so that one can see directly the amount and direction of the average daily wind movement. The labor is light, simple, and quite mechanical when the appropriate scales are computed, and is suitable for women.

In working up older observations one may appropriately plot the observations for the entire year on one sheet, indicating the different months by their proper numbers, as shown in figure 3 and Table 1.

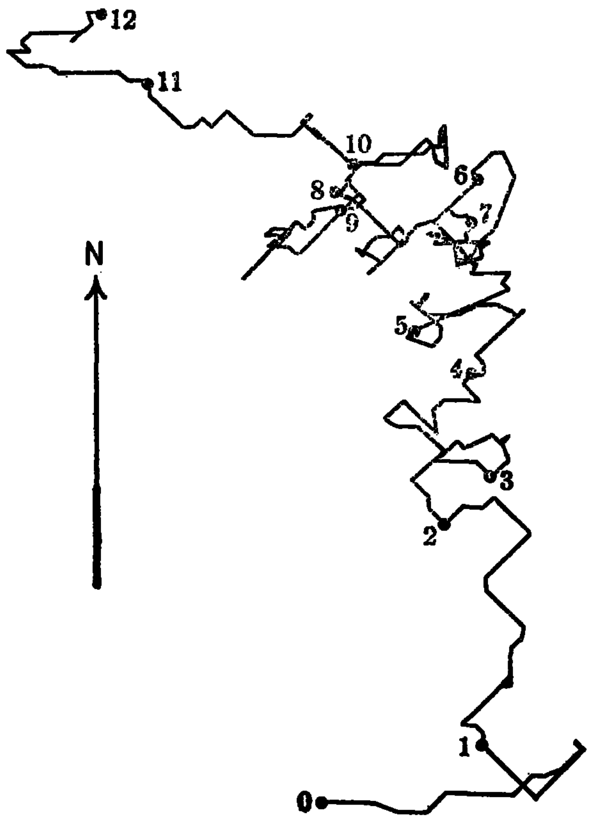

FIG. 3.—Tracing by the device shown in figure 1. Data: Wind vectors for Skara, Sweden, 1910. Nos. 1, 2, 3, etc., indicate ends of plots for respective months; the line 0-12 gives direction and mean wind movement for the station for the year.

In working up more recent observations the wind diagrams for several stations for the month in question may be plotted side by side on the same sheet. The results would be shown in tabular form as follows—

TABLE 1.—*Results of wind observations at Skara in 1910.*

[Lat. 58° 21′ N., long. 13° 27′ E. Altitude, 115 meters.]

[Compare plat in fig. 3.]

Month.	Direction of movement.	Magnitude of movement.	Mean 24-hour movement.	Mean movement.
	Figure 2.	*Km.*	*10^4 meters.*	*M/sec.*
I	2	3,800	12	1.4
II	11	5,200	19	2.1
III	5	1,400	5	0.5
IV	11	2,400	8	0.9
V	16	1,700	5	0.6
VI	7	3,700	12	1.4
VII	29	1,200	4	0.4
VIII	18	3,300	11	1.2
IX	32	400	1	0.2
X	8	1,100	4	0.4
XI	18	5,100	17	2.0
XII	14	1,900	6	0.7
Year	12	16,900	4.6	0.54

and then entered on the monthly maps. It will be convenient in this procedure to represent the monthly wind values as arrows whose lengths show the mean air movement for 24 hours, according to the scale of the map. Of course the lengths of these arrows will be quite independent of the units (kilometers or miles) used in computing them.

Figure 4 shows a wind chart of Europe for January, 1913, made in this way. The regularity and continuity of the independently determined vectors on this chart is a proof of the reliability of the method.

This method has been little used heretofore and will give us many new ideas concerning meteorological phenomena. In order to prove this I will discuss the charts somewhat more fully. Heretofore it has been held generally that the prevailing winter winds of Europe were southwesterly because the winter climate of Europe is [supposed to be] very much dependent on the temperature of the Gulf Stream of the North Atlantic Ocean. The air temperature in Sweden is indeed in winter 12°C., in Finland 10°C., and in Germany 8°C. higher than the normal mean temperature for the latitude. Also Prof. O. Pettersson has clearly and incontrovertibly proven that during the years in which the North Atlantic Gulf Stream was specially warm, the climate [weather?] of Europe was also mild, and vice versa.

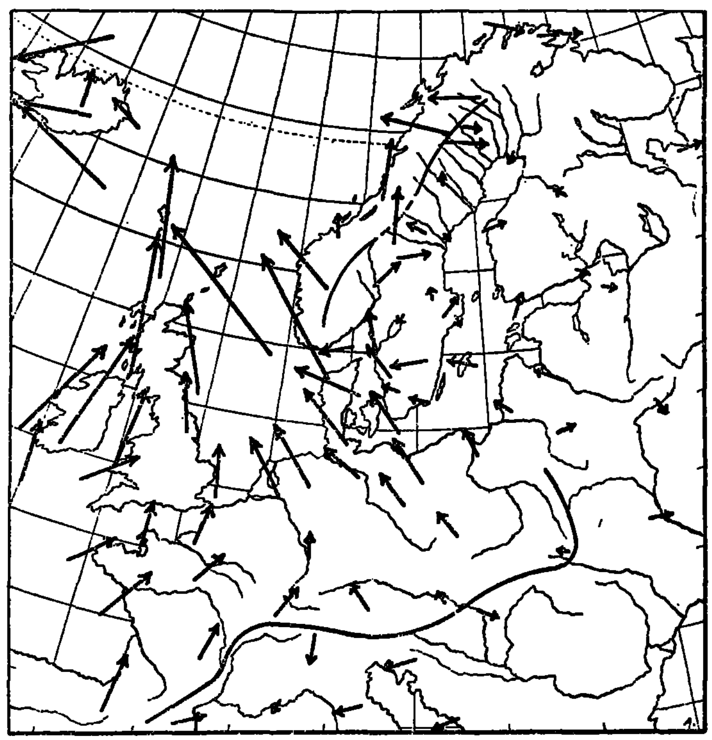

FIG. 4.—Mean 24-hour surface wind movement and direction in January, 1913, over western Europe. (Wind movements are indicated by length of arrows according to the scale of the map.)

The map, figure 4, shows that, at least in January, 1913, the air did not move from the southwest to the northeast, but rather from the southeast to the northwest. The air that overflowed Scandinavia and Germany in January, 1913, therefore did not come from the Atlantic Ocean but from the interior of the continent. Yet Europe was far warmer in this month than the normal mean temperature for its latitude.

We are thus obliged to think that the warmth from the North Atlantic Ocean is not carried to Europe by the surface winds but by those at higher levels. We may liken Europe and the North Atlantic Gulf Stream to a room with a stove in its northwest corner. When the stove is heated the warm air rises and spreads itself over the upper part of the room, gives off its heat, and then sinking, follows the floor back to the stove. Thus a warmer northwest wind blows along the ceiling of the room and a cold southeast wind blows along the floor, as may be easily proven by the use of tobacco smoke and a thermometer. Similarly, during the winter a warm northwesterly wind will blow at high altitudes over Europe and colder southeasterly winds will move along the surface. It is this lower southeasterly wind that appears on the chart, figure 4.

A vertical section through the atmospheric circulation between the North Sea and the Alps in January, 1913, would therefore appear somewhat like figure 5. Dr. O. Krogness, director of the mountain observatory on Haldde, 900 meters high, on the northern coast of Norway, has sent me a large number of observations, among others those of January, 1913, which lend great support to this concept of the air circulation over Europe. At Haldde the wind was quite predominantly from the northwest, while at the base of the mountains a southeasterly wind predominated. At the same time the air temperature was several degrees higher at the summit than at the base. Evidently the air warmed over the sea flowed toward the continent at a high altitude while the cold air from the continent flows seaward beneath it.

At Haldde the surface dividing the upper warm from the lower cold air currents stands at an altitude of less than 900 meters. Farther inland, in the Swedish mountains, I have found this surface at an altitude of about 1,200 meters, while it appears from kite and balloon observations at Lindenberg that it there lies between 2,000 and 3,000 meters high. It is therefore inclined and dips toward the warm sea as is indicated in figure 5.

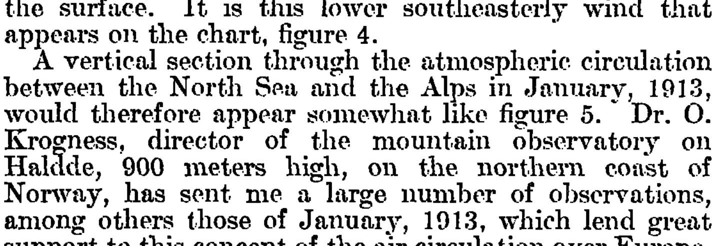

Fig. 5.—Atmospheric exchange in winter between Europe and the North Atlantic ocean.

I have produced this dividing surface experimentally on a small scale and there also have found that it is inclined.[2] Because of the temperature inversion and the sudden change in density at this surface as well as its oblique position it embraces a great number of Bjerknes solenoids. If we estimate the heating of the air over the North Atlantic Ocean at 9°C. and put the difference of altitude of the dividing surface from the Alps to the North Sea as 3,000 meters, then the surface will contain about 10^7 solenoids.

According to figure 4, the mass of air flowing to the North Sea may be estimated as 5 cubic kilometers per second or 5×10^6 metric tons, which would give an energy of about 7×10^9 horsepower.[3]

In the circulation indicated in figure 5, the air is thus seen to pass through a Carnot cycle, by means of which this enormous amount of energy is transformed from heat into wind. It is therefore this tremendous amount of energy that maintains the great air circulation between the North Atlantic Ocean and Europe and at the same time moderates the winter climate of Europe. It is also this circulation that causes Europe's winter storms and winter precipitation. This wind-making machine is surely well worth investigating.

Having revealed, by means of the map, figure 4, the probable cause of the mighty southeasterly air current across Europe during January, 1913, we will consider still other details of the chart. The first thing that attracts our attention is that the air flows outward on either side of all mountain ranges. From the Alps it flows both southward to the Mediterranean and northward to the North Sea; from the Carpathians eastward toward the interior of Russia as well as westward to the North Sea; from the Scandinavian ranges westward toward the North Sea as well as eastward toward Finland. The cause of this outflow from the mountain regions is evidently thermal radiation skyward which cools the mountains and also the air in contact with them. By this means the specific gravity of the mountain air becomes greater than that of the surrounding air and sinks through it, following the mountain sides. Furthermore, we see that the broad warm seas possess considerable aspirating force. Even the Mediterranean draws a considerable mass of air toward itself, but the warm North Atlantic Ocean draws the greatest quantity. This aspiration is evidently due to the warming of the air over the warm oceans, whereby it becomes specifically lighter and is pushed upward by the surrounding denser air that pushes in beneath.

This descent of the cooled air from the mountains and forcing upward of the warmed ocean air evidently sets up the circulation shown in figure 5. We can picture the process as follows: The temperature conditions first produce a special pressure distribution as the vertical interval between two isobaric surfaces is always proportional to the absolute temperature of the intermediate air, therefore the isobaric surfaces lie closer together in the cold mountain region than over the warm sea. The result is that the pressure gradient at lower altitudes is from the mountains toward the sea, while at higher levels it is in the opposite direction. At the surface of the earth the air will flow, therefore, from the mountains toward the sea and at the higher levels the air flows from the sea toward the mountains.

The cold, heavy air flowing down from the mountains thereby generates kinetic energy just as does a river flowing from a higher to a lower level. Like results are produced by the light air ascending over the ocean. The enormous mass of air and the considerable difference of level produces the great amount of wind energy resulting from the movement. It is clear, however, from this that the cooling of the air must occur at levels higher than where the warming takes place, otherwise no permanent circulation can result therefrom. For this reason no air circulation takes place between the warm North Atlantic Ocean and the Arctic ice. The higher the source of cold lies in comparison with the source of heat, the more intense the air circulation will be.

The outflow from the mountains and the aspiration by the sea, shown in figure 4, naturally also occur in other parts of the earth. The warm North Atlantic Ocean is surrounded by a whole series of mountain ranges—the Pyrenees, Alps, Carpathians, Scandinavian ranges, and those of Spitsbergen and Greenland. Between the North Sea and each of these mountains there is without doubt an air circulation similar to that shown in figure 4. It may be compared with a kettle that is

[2] *Sandström.* The origin of the wind. Monthly Weather Review, April, 1915, 43: 161-163.
[3] *Sandström.*, op. cit., p. 163.

heated under its center. The water in the pan then begins to circulate. It becomes warm in the center, rises to the surface, spreads out to the sides of the kettle where it is cooled, and sinking follows the bottom back to the center. (See fig. 6.)

way of the North Sea these Norwegian falling storms would evidently become of much greater intensity and longer duration. We thus see how considerable is the influence of topography on the occurrence of storms.

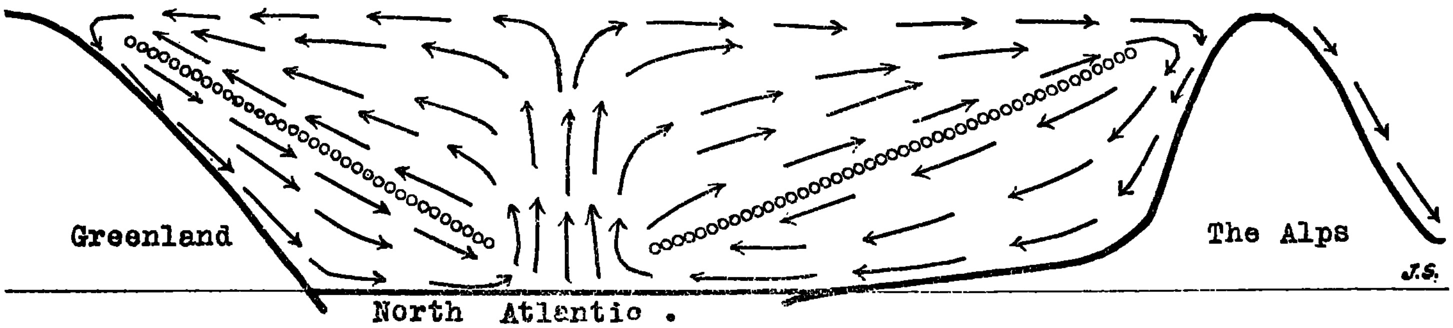

FIG. 6.—Vertical section through the atmospheric circulation over the North Atlantic in winter.

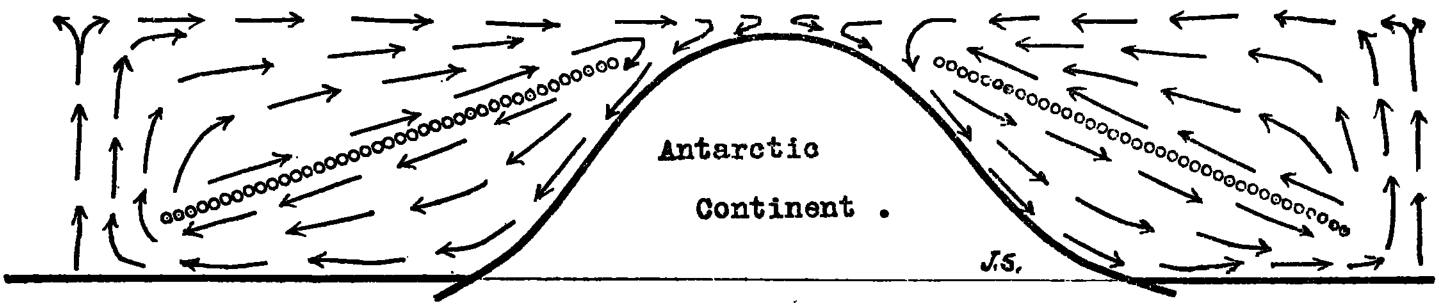

FIG 7.—Vertical section through the atmospheric circulation about Antarctica during the southern winter.

We find another condition in the South Polar region. Here the cold mountains are at the center, surrounded by the warm sea. But here also the rule holds that the air from the cold continent flows outward on all sides, following the surface. On the surrounding oceans the air is warmed and saturated with water, after which it rises and moves along the higher levels to Antarctica whose ice fields are fed by its moisture. (See fig. 7). The extraordinarily constant southwest wind which the Swedish South Polar Expedition of 1902–1903 met with here during the antarctic winter, maintained for weeks a velocity of 20 to 30 meters per second and indicates that the cold seaward-moving air current must be of great depth and strength.

We should then notice somewhat the details of figure 4. We see how the southeasterly air current prefers the easiest way across the North Sea and how it curves around the south end of mountainous Norway. In the narrow passage between Norway and Scotland the air movement is strongly accelerated. On the east side of the Scandinavian mountain range the heavy cold air piles up and forms a sort of aerial lake, with small velocities generally directed eastward. However, in the middle of this extended mountain range at Storlien, where its summit is lowest, the air flows westward from the east side of the ridge also. Evidently here the continental air overflows the ridge. Sometimes probably a portion of the cold-air sea dashes over the higher part of the range also and rushes down the west side of the mountains. These are the times of the extraordinarily violent easterly storms which I have met with in that region in winter and which stopped just as suddenly as they started.[4] Were it not for the open sluice-

[4] *Sandström* in Bull. Mt. Weather Observatory, Washington, 1912, 5: 84-85.—EDITOR.

Many other important conclusions may indeed be drawn from the map in figure 4. What has already been done should be sufficient to awaken in the reader interest for a rational method of working up wind observations in different countries and at different seasons. This is the object of the present paper.

WATERSPOUTS OBSERVED OFF CAPE SAN LUCAS.

By WILLARD J. FISHER.

[Dated: New Hampshire College, Durham, N. H., Nov. 27, 1915.]

The following is an extract from my log on a voyage from New York to San Francisco last summer [1915] on the steamer *Kroonland*. The directions are approximate compass directions, taken with a pocket compass on the bows of an iron ship. Unfortunately, my supply of photographic films was exhausted and I could take no pictures. The sketches, figures 1 to 3, were made in my log immediately after dinner on the day of the observation; faithful tracings of them are reproduced here.

July 22, 1915:

ϕ=17°40′ N., λ=102°36′ W. at noon.

July 23, 1915:

ϕ=20°46′ N., λ=107°36′ W. at noon.

Crossing the broad entrance to the Gulf of California. Saw, 9 a. m. to 11:30 a. m., two long banks of clouds, extending N.-S. clear out of sight, moving about W., as they were several miles apart and they were caught up with, but only slowly. They were cumulus clouds; a section looked about like that shown by figure 1, which is looking northward. The air currents which fed them seemed to move as the dotted arrows. From below there hung down tornado funnels of various sizes and various stages of development, from mere pimples to long well-grown vortices; but none of them reached more than halfway to the sea. From one cloud a smart shower fell on us as we passed under. The funnels were formed where the upward growth of the